International Journal of Mechanical and Production
Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 2249-8001
Vol. 8, Issue 6, Dec 2018, 177-186

STUDY AND PERFORMANCE ANALYSIS OF VERTICAL AXIS WIND TURBINE USING REDUCED INCLINED ARM ANGLE USING AEROFOIL SHAPE

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ABSTRACT

The performance of the vertical axis wind turbine is characterized and it is analyzed. In this research work, NACA 0018 aerofoil structure is used for modeling the wind turbine blades. The arm length of the blades is reduced. The performance is analyzed using the ANSYS FLUENT. The performance is carried by varying the arm angle to 30, 45, 60 degree and study the comparative results performance of the three inclined angle turbine blade of same length and chord length. Turbulence model is used for the simulation of the wind turbine blade. Turbulence, pressure, and vorticity of the wind turbine are taken for the performance analysis and results is reported for each arm inclination angle.

***KEYWORDS:** Reduced Arm, Vertical Axis Wind Turbine, Turbulence Model & Performance Study*

Received: Jul 19, 2018; **Accepted:** Aug 09, 2018; **Published:** Oct 26, 2018; **Paper Id.:** IJMPERDDEC201821

Original Article

INTRODUCTION

The wind turbines are used for the conversion of wind energy into mechanical energy. There are different types of wind turbines are there. A vertical axis wind turbine is one of them used for commercially. The shape of the blade is changed so that the energy loss can be reduced. To that, the aerofoil shape blade is used for this research.

STRUCTURAL INTEGRITY AND PROBLEM DEFINITION

Problem Definition

- In earlier, turbine blade is designed using a flat plate. The main disadvantage in this method is increased drag.
- The major problem with the VAWT is that it is difficult to perform at high altitude.[2]
- It needs an initial force to start the turbine.

Modeling of Vertical Axis Wind Turbine

The modeling of the Vertical axis Wind Turbine starts with a selection of an Airfoil profile. NACA 0018 Airfoil was chosen for this design. That airfoil was imported into Solid works software. Vertical Axis Wind Turbine has also inclined arms and horizontal Arm.

The geometry of the inclined-arms concept implies the presence of two inclined arms with airfoil-shaped cross-sections. The inclined arms are joined to a horizontal arm that connects the blades to the hub. The complete turbine configuration consists of three rotating “elements” mounted on the hub.

In the study presented here, each element is formed by,

- A NACA 0018 straight, untwisted vertical blade, with 20cm of the chord.
- 2 inclined arms whose cross-section has the same profile of the vertical blade; their external tip is attached at some point along the vertical blade, and each inclined arm forms a 30^0 angle with the blade. This Angle of Inclined arms varies such as 30^0, 45^0, 60^0.
- An inner horizontal arm, with NACA 0018 profile and 12cm of the chord, connecting inclined arms to the hub.

Figure 1: NACA 0018

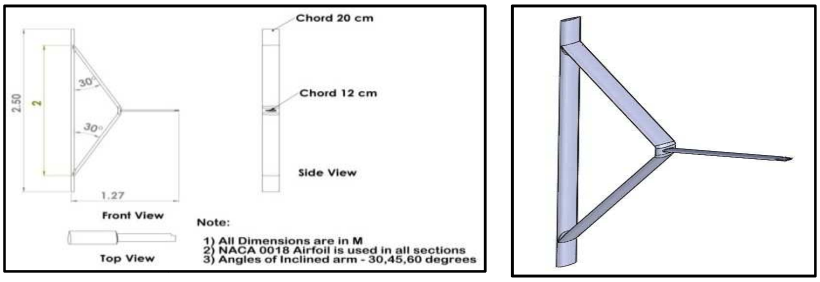

Figure 2: Arm at 30 Degree

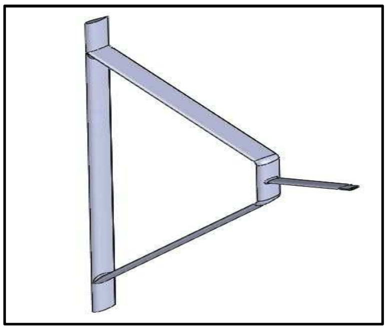

Figure 3: Arm at 45 Degree

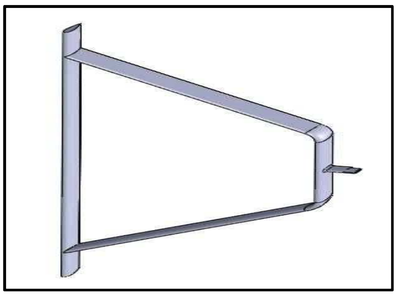

Figure 4: Arm at 60 Degree

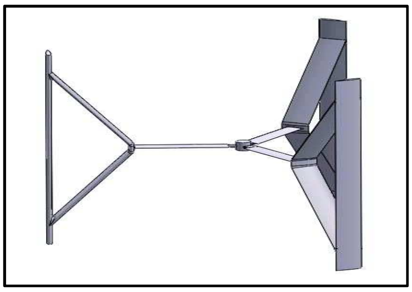

Figure 5: Vertical Axis Wind Turbine with at 30 Degree

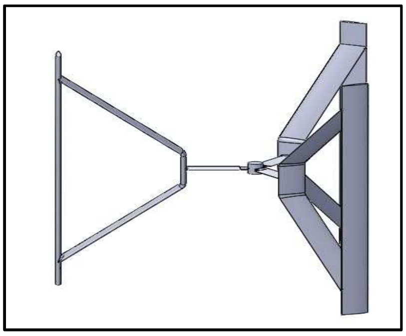

Figure 6: Vertical Axis Wind Turbine with at 45 Degree

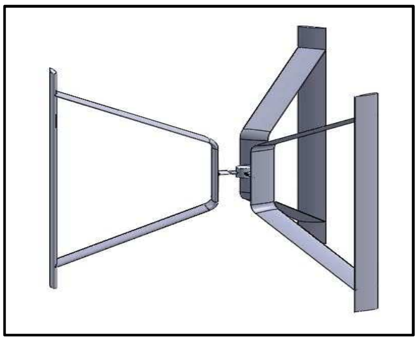

Figure 7: Vertical Axis Wind Turbine with at 60 Degree

NUMERICAL ANALYSIS

The domain is created over the model with the following parameters:

- Length of the domain = 40 m
- Height of the domain = 70 m
- Width of the domain = 60 m
- Distance from an inlet to Blade = 20 m
- Distance from top wall to blade = 35 m

By considering these parameters the domain for analysis is created as shown in figure 2. The left side image shows the domain creation and the right side image shows the 3D domain created for the object.

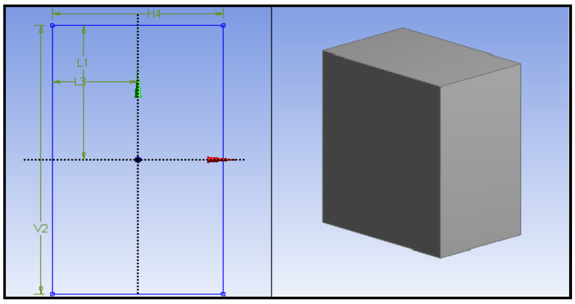

Figure 8: Domain of the Model

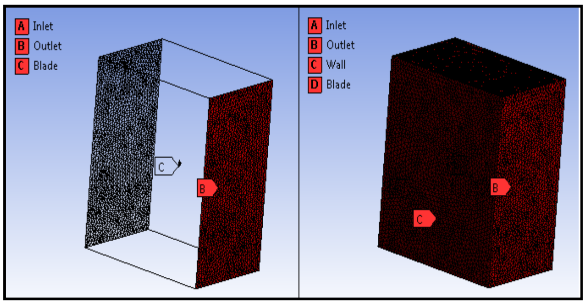

Figure 9: Section Naming

Solver Settings

The problem of wing numerical analysis requires the solver settings to be completed before starting the simulations. The solver setting includes the type of solver (3D or 2D), the viscous model, boundary condition and solution controls. The inlet of the wind tunnel is indicated by the term ‘Velocity inlet’, while the outlet of the wind tunnel is termed as ‘Pressure outlet’. The fluid properties were calculated taking into account the temperature and density of the average ambience condition. The solver settings and boundary condition for both the benchmark simulations are shown in Table 1, Table 2 and Table 3.

Table 1: Solver Setting

CFD Simulation	3D
Solver	
Solver	Pressure-Based
Space	3D
Formulation	Implicit
Time	Steady
Velocity Formulation	Absolute
Gradient Option	Cell-Based
Porous Formulation	Superficial Velocity

Table 2: Viscous model and Turbulence Model Settings

Viscous Model	
Turbulence Model	Spalart-Allmaras
Near-Wall Treatment	Standard Wall Functions
Operating Conditions	Ambient

Table 3: Boundary Condition

	Boundary Conditions	
Velocity Inlet	Magnitude (Measured normal to Boundary)	12 m⁄s (constant)
	Turbulence Specification Method	Modified turbulent viscosity
	Modified Turbulent Viscosity(m^2/s)	0.001
Pressure Outlet	Gauge Pressure magnitude	0 pascal
	Gauge Pressure direction	normal to boundary
	Turbulence Specification Method	Modified turbulent viscosity
	Backflow Modified Turbulent Viscosity(m^2/s)	0.001
Wall Zones	No Slip	
Fluid Properties	Fluid Type	Air
	Density	$\rho = 1.225$ (kg⁄m^3)
	Kinematic viscosity	$v = 1.7894\times10^{-5}$ (kg⁄(m·s))

SIMULATION RESULTS

The major characters in terms of aerodynamics are pressure, velocity, turbulence, and vortices. Apart from the forces, the characters must also satisfy the better performance conditions. The below discussion shows the aerodynamic characters for blade model with various degrees of inclination.

Table 5: Aerodynamic Parameters

Angle	Pressure		Velocity		Turbulence		Vortices	
	Min	Max	Min	Max	Min	Max	Min	Max
30	8.76×10^1	2.03×10^1	0.15	23	1.67×10^{-4}	3.37×10^{-3}	6.04×10^{-5}	1.82×10^3
45	8.74×10^1	5.5×10^1	0.84	20	4.05×10^{-4}	3.34×10^{-3}	5.23×10^{-5}	1.3×10^3
60	8.6×10^1	2.3×10^1	0.86	18.2	4.42×10^{-4}	3.05×10^{-4}	6.93×10^{-5}	8.42×10^2

Pressure Distribution

The pressure distribution over the blade is shown in below figures. The figures represent the maximum and minimum pressure over the blade. The contours show that the pressure distributions over the model, from this model it’s clear that the pressure over the 60-degree inclined blade has a better performance. The pressure distribution is uniform towards all the points on the blade surface so as the model could produce a higher rotation.

Velocity Distribution

The velocity distribution over the blade is shown in below figures. The figures represent the maximum and minimum velocity over the blade. The blade model has an improved in velocity distribution over the blade for a 30-degreemodel. Its can be seen clearly in the velocity vectors. Whereas the model with the other inclinations has an acceptable velocity value where there is not much decrease in the velocity values.

Turbulence over the Blade

Turbulent flow is a flow regime characterized by chaotic property changes. This includes low momentum diffusion, high momentum convection, and rapid variation of pressure and flows velocity in space and time. The turbulence distribution over the model is as shown below.

Vortices over the Blade

The vorticity is a pseudo vector field that describes the local spinning motion of a continuum near some point, as would be seen by an observer located at that point and traveling along with the flow. The vortices over the model must be

low so that it won’t get induced due to the induced drag. The induced drag is a main parameter over the model.

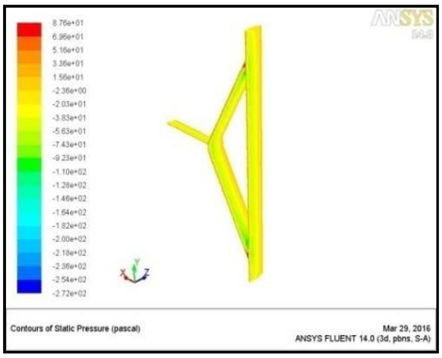

Figure 10: Pressure Distribution for 30 Degree

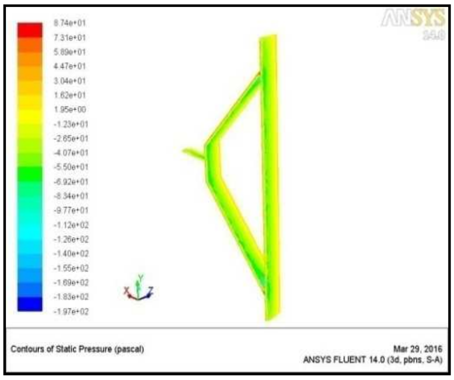

Figure 11: Pressure Distribution for 45 Degree

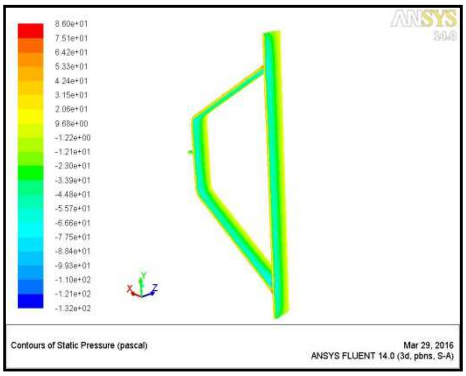

Figure 12: Pressure Distribution for 60 Degree

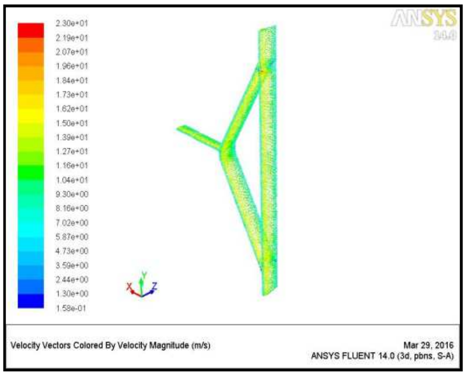

Figure 13: Velocity Distribution for 30 Degree

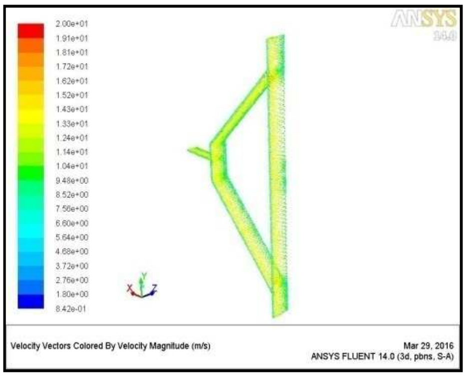

Figure 14: Velocity Distribution for 45 Degree

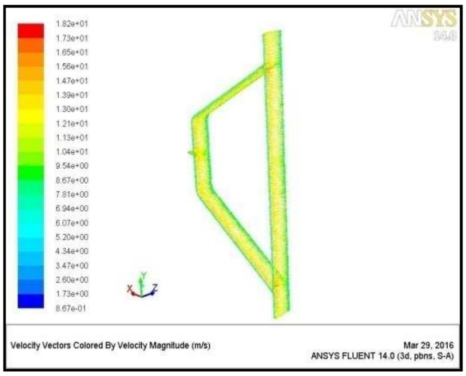

Figure 15: Velocity Distributions for 60 Degree

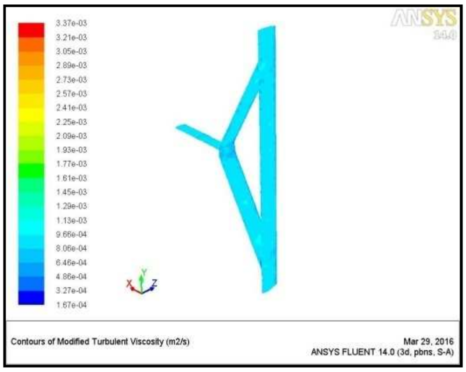

Figure 16: Turbulence for 30 Degree

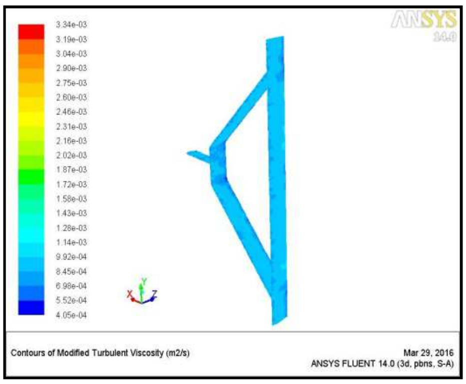

Figure 17: Turbulence for 45 Degree

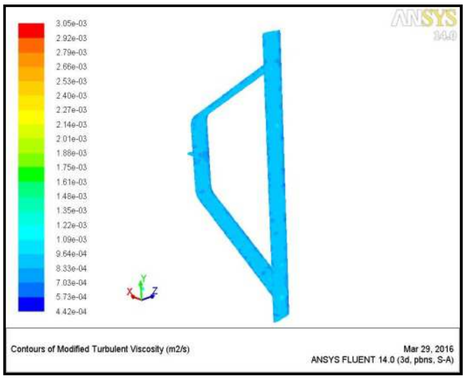

Figure 18: Turbulence for 60 Degree

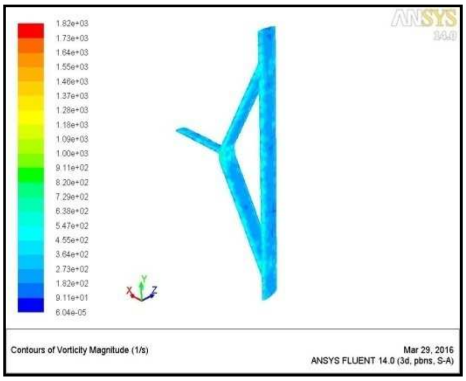

Figure 19: Vortices for 30 Degree

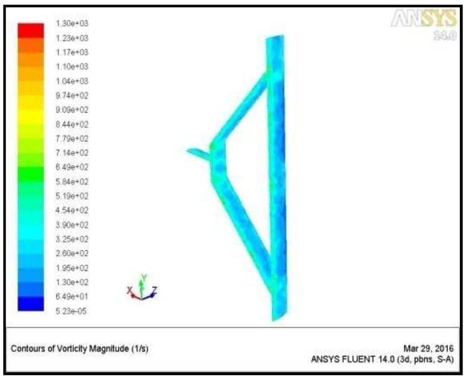

Figure 20: Vortices for 45 Degree

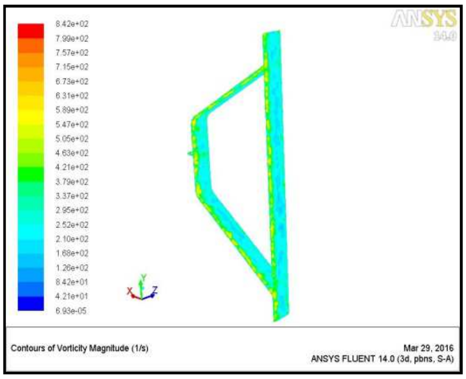

Figure 21: Vortices for 60 Degree

CONCLUSIONS AND RESULTS

From the simulation, the parameters like pressure, velocity, turbulence, and vortices are computed and the contours for those models are shown in the above figures. From the results, it's clear that the model with the 60-degrees inclination has a low turbulence and vortices so that the model is little free from the resistance force. But the velocity distribution over the 30-degrees model looks effective in terms of the velocity parameter.

From the result value and contour plots of the Spalart-Allmaras model wind turbine which arm at 60-degrees has less turbulence and vorticity with respect to the velocity of other two. Thus the VAWT with aerofoil is inclined to 60-degrees gives high performance.

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